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An UWB Bandpass Filter with Triple-Notched Band using Embedded Fold-Slot Structure

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ABSTRACT

In This paper, an ultra-wideband bandpass filter based on embedded fold-slot structure and slotted step impedance resonator (SSIR) is presented. The embedded fold-slot will be comprehensively described. The proposed filter has triple notched in the passband, resulting from the embedded fold-slot structure. The center frequencies and bandwidths of notched bands can be controlled by adjusting dimensions of the embedded fold-slot. The wider upper stopbands caused by slotted resonator characteristics have been also obtained. The simulated and experimental results show triple-notched band around 340 MHz, 306 MHz and 573 MHz, respectively. High stopband performances with better than 20 dB for a frequency range up to 18 GHz have also been obtained.

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INTRODUCTION

The Ultra-wideband (UWB) frequency between 3.1 to 10.6 GHz for a variety of applications for instance indoor and hand-held wireless communication system has been authorized by the U.S. Federal Communications Commission (FCC) since 2002 (Aiello and Rogerson, 2003). The various techniques have been recently developed for UWB bandpass filters. Stepped impedance resonators with multi-mode resonators (MMRs) were used for UWB bandpass filters, resulting in size reduction and improved stopband performance (Zhu *et al*., 2005). The interdigital coupled lines were formed to assign their transmission zero towards the fourth-order resonant frequency of the MMRs (Sun and Zhu, 2006; Meeloon *et al*., 2009). Most of these UWB bandpass filters have superior performance and are suitable for implementation. Moreover, covering wide frequency, the UWB systems can be interfered by the existing undesired radio signals, such as wireless local-area network, WiMAX and RFID. In order to avoid interferences from the undesired signals, UWB bandpass filters with triple-notched band have been required.

Generating of notched bands to reject these signals has been proposed in different methods, such as adding stubs to the arms of interdigital coupled line (Shaman and Hong, 2007), using embedded structures in the feed line (Lin *et al*., 2010), and adding a parasitic coupled line which resulted in a narrow notch band as proposed in (Pirani *et al*., 2010). The UWB bandpass filter with compact size and notched band has been designed by using embedded step-impedance resonator (Ghatak *et al*., 2011). Many researches proposed dual-notched bands with asymmetric coupling strip (Song and Xue, 2010) and designed on a two layered structure using conductor-backed coplanar waveguide (Mao *et al*., 2009). The multilayer techniques, including LCP and LTCC technology, had not only helped reject undesired radio signals but also reduced size of filter structures (Hao and Hong, 2009; Oshima *et al*., 2010).

In this paper, an UWB bandpass filter with triple-notched band and improved stopband performance is proposed. It consists of two slotted step impedance resonators (SSIR) driven by inter digital coupled lines at both ends of the resonator to improve the stopband performances. Also, it has embedded fold-slot structure at the input, output feed lines and resonator, which can create notched bands. In section 2, the UWB bandpass filter will be designed and optimized. The experimental verification and measured results of the proposed UWB bandpass filter will be described in details in section 3. Finally, our conclusions will be given in section 4.

2. Filter Design:

Fig.1 shows the proposed UWB bandpass filter, which creates triple-notched band with embedded fold-slot at

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the input, output feeds and resonator. The UWB bandpass filter using MMR resonator and interdigital coupled line for enhancing coupling degree has been studied in the literature (Zhu *et al*., 2005). It has been widely used as a capacitive coupling with two 50 Ω feed lines in the UWB bandpass filters. However, it must be redesigned to achieve design-specified coupling factor between two adjacent line resonators. To achieve a tight coupling degree, the strip and slot widths must be reduced. I therefore design and optimize the interdigital coupled line on the RT/Duroid 3003 substrate with a dielectric constant of 3.0, a thickness of 1.524 mm, and a loss tangent of 0.0013. By using IE3D program (Zeland Software, 2003), it results to $l2$ = 6.45 mm, $w2$ = 0.5 mm, and g1 = 0.2 mm, as shown in Fig.1. It has been found that this new coupled line has better superior passband characteristics than conventional one.

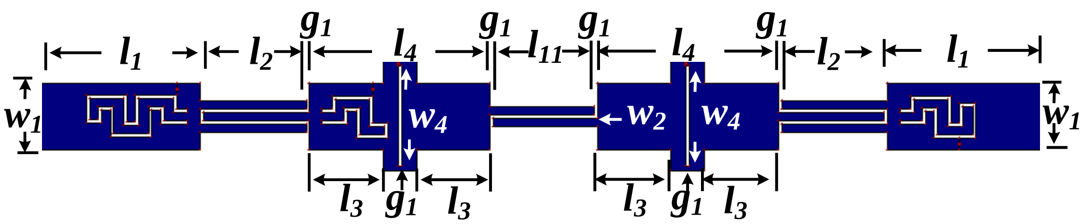
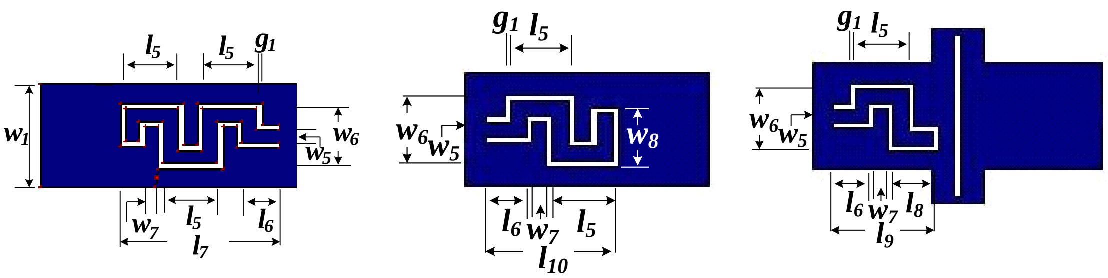


Fig. 1: The proposed filter with triple-notched band



(a) (b) (c)

Fig. 2: The embedded fold-slot structures (a) input feed (b) output feed and (c) resonator

Also, the conventional UWB bandpass filter (Sun and Zhu, 2006), using λg/2 microstrip resonator, has inherently spurious resonant frequencies at $2f_o$ and $3f_o$, where f_o is the fundamental frequency (6.7 GHz), which may be too close to the desired passband. MMR is formed by attaching slotted resonators in the middle of step impedance resonator for extending stopband in the upper frequency to be larger than 10 dB over 12 GHz to 18 GHz. Thus, microstrip SSIRs have been proposed as shown in (Meeloon *et al*., 2009) for higher stopband performances.

This filter was implemented on the RT/Duroid 3003 substrate. The IE3D program has been used to determine the filter performances. The optimized dimensions of the slotted resonators and the interdigital coupled lines have been obtained in the previous work (Meeloon *et al*., 2009) including l_2 = 6.45 mm, l_3 = 5.4 mm, l_4 = 11.0 mm, w_1 = 4.0 mm, w_2 = 0.5 mm, and w_4 = 5.5 mm. Also, the optimized dimensions of the embedded fold-slot at the feed line and resonator for 5.6 GHz, 7.3 GHz and 9.3 GHz with triple-notched bands have been obtained to be l_1 = 10.0 mm, l_5 = 2.12 mm, l_6 = 1.47 mm, l_7 = 5.94 mm, l_8 = 1.53 mm, l_9 = 3.82 mm, l_{10} = 4.44 mm, l_{11} = 6.5 mm, w_5 = 0.6 mm, w_6 = 2.1 mm, w_7 = 0.52 mm w_8 = 1.7 mm and g_1 = 0.2 mm. These all parameters are in Fig.1 and Fig.2.

In order to create triple-notched band of the filter, embedded slot at the input, output feeds and resonator have been proposed. The RT/Duroid 3003 substrate has been used in this study. Fig.3 (a) shows the part of embedded slot feed and its frequency responses of S_{21} when varying the length L of the embedded slot from 5 to 10 mm. It can be found that a center frequency of notched frequency can be adjusted from 9 GHz down to 5 GHz. When increasing the width W of the embedded slot while keeping the center frequency to be the same, the bandwidth of notched band is increased as shown in Fig.3 (b). The embedded slot structure derives from varying the width W of the embedded slot from 0.6 to 1.6 mm and varying the length L of the embedded slot from 8.593 to 8.393 mm. It can be clearly seen that, at 3 dB, bandwidth of the notched band is increased. Therefore, by tuning the length and width of the embedded slot, center frequencies and bandwidth of notched band can be easily adjusted. Embedded slot is thus suitable for use in the UWB bandpass filter when a notched band is required.

To investigate the notched mechanism, the simulated current distributions of embedded structure at resonant notched frequency of 5.6 GHz, 7.3 GHz and 9.3 GHz are shown in Fig.4. It is observed that the current distribution cannot pass through the proposed structure.

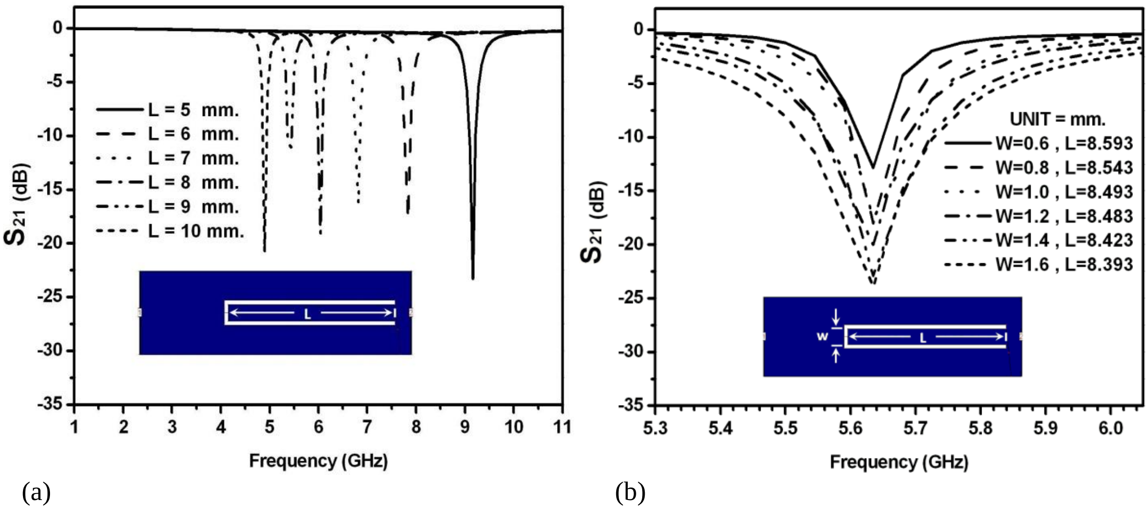


Fig. 3: S_{21} magnitude responses of the embedded slot structure with a slot of 0.2 mm when (a) varying L (b) varying W

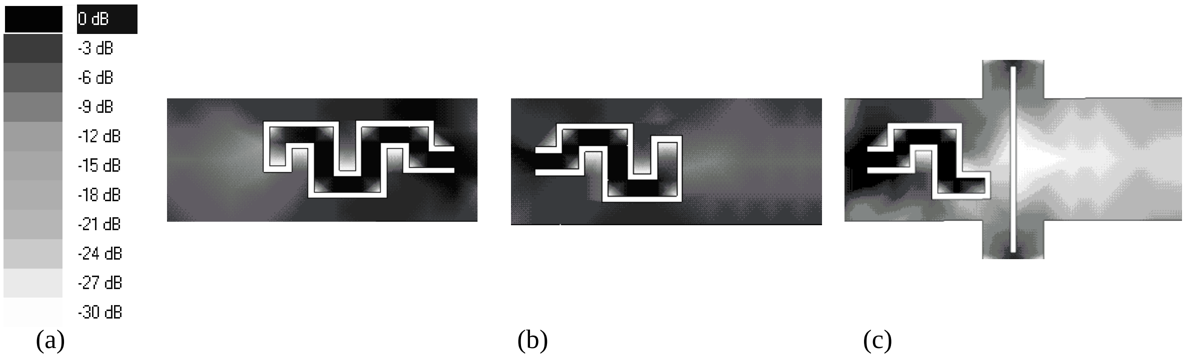


Fig. 4: Current distributions of notch band at (a) the 5.6 GHz feed line (b) the 7.3 GHz feed line and (c) the 9.3 GHz resonator

Experimental and Measured Results:

Fig.5 shows the photograph of the fabricated SSIR filter for triple-notched band. Fig.6 shows a comparison of measured and simulated responses of the SSIR filter with triple-notched band. It can be found that the measured results agree with the simulation expectations, confirming that the proposed filter is capable of generating triple-notched band, having good insertion losses within the passband and also widening the upper stopband. The measured return and insertion losses are found to be lower than 10 dB and higher than 3 dB, respectively over desired UWB passband. The notched frequencies of about 5.6 GHz, 7.3 GHz and 9.3 GHz have a bandwidth of about 340 MHz, 306 GHz and 573 MHz, respectively. The proposed filter shows triple-notched band and improved upper stopb and performances with high insertion loss. The upper stopband with the insertion loss lower than 20 dB occupies an enlarged range of 12 to 18 GHz. The group delay of filter slightly varies between 0.2 to 0.3 ns in the passband. Moreover, the proposed filter exhibits notched bands and a wide upper stopband with values of S_{21} lower than 50 dB at 13 GHz, 15 GHz and 16 GHz, respectively. These superior stopband performances are caused by the stopband characteristics.

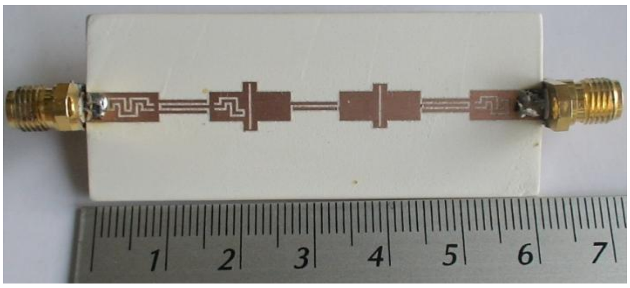


Fig. 5: Photograph of fabricated UWB filter for triple-notched bands

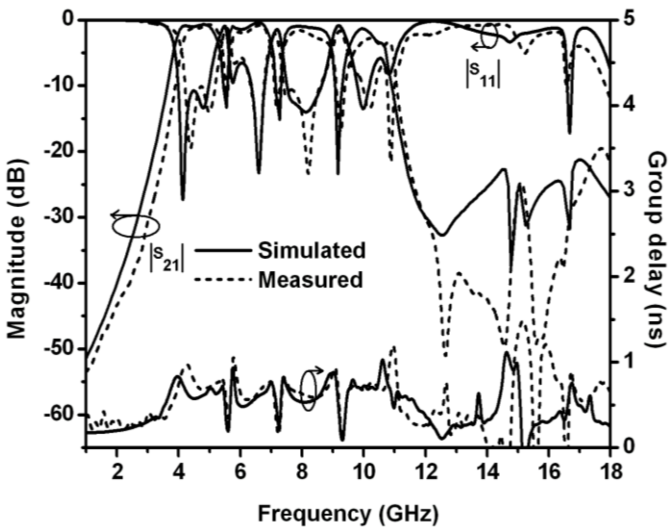


Fig. 6: Comparison of measured and simulated responses of the filter with triple-notched bands

Conclusion:

The slotted step impedance resonator and embedded fold-slot structure for UWB bandpass filter with improved upper stopband performances and created triple-notched band have been presented and implemented. By properly forming SSIR together with two interdigital coupled lines at both ends and embedded fold-slot at feed line and resonator, the filter is constructed and its performances are extensively investigated in simulation and measurement. The proposed filter demonstrates its capabilities in generating triple-notched band with the embedded fold-slot structure and suppressing spurious responses with slotted resonator. Also, it can widen the upper stopbands.

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